Stephanie Cao
CS399
2-page Abstract Peer Review

"A Tale of Two Provers" :

Comparing Program Verification Techniques in Dependent Haskell and F*

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February, 2018

1 Introduction

We as programmers write many programs every day, but how do we make sure that these programs indeed perform as intended, and how can we guarantee that these programs cannot be used to perform unintended tasks ?

Program verification is a technique, which uses formal mathematical methods to prove the correctness of a software program or system, with respect to a formally defined or inferred specification. It can detect most system vulnerabilities and program bugs at compile time. There are two mainstreamed approaches to verify programs : those based on Type Theory (TT), as in Coq[3], Agda [9], and Idris[2] [1], and others based on Satisfiability Modulo Theory (SMT), such as Liquid Haskell [11], Dafny[7], and F*[10].

TT-based Dependent Haskell and SMT-based dependent-and-refinement-typed F* each represents a unique and effective program verification technique. They are similar in that they both aim towards a verification-based yet general-purposed programming language, but they are noticeably different in their unique approaches to categorize programming effects. Working in both languages for a semester, I find promising properties that I believe might lead to potential collaborations. However, to my knowledge, and with consultation with Eisenberg and Swamy, the two communities generally conduct research separately and have rarely explored each other's approaches in-depth.

In my undergraduate thesis, I aim to introduce the two verification-oriented programming languages, namely Dependent Haskell and F*, present their unique type system designs with concrete examples, and give a detailed comparison from a combination of theoretical and practical standpoints. I expect my research to setup a solid foundation for potential collaborations across the two communities, and to possibly propose promising future research directions in program verifications for the general Programming Languages community.

2 Background and Related Work

Haskell is a strongly and statically typed, purely functional programming language. For a long time, Haskell researchers strive to add dependent types into Haskell, as it introduces much more precise expressions of program specifications. Although Haskell hasn't yet supported dependent types in full, several extensions on its current type system have made exceptional progresses. In 2012, Eisenberg and Weirich introduce the `singletons` library that essentially achieves dependently-typed programming in Haskell[5]. With the common goal of introducing full-fledged dependently-typed Haskell, Gundry and Eisenberg both implemented dependently-typed Haskell using GADTs and type families where Eisenberg's Dependent Haskell is an extension to Gundry's work.[6][4]. Besides type families that encode

1. Specifically, all three languages are based on Martin-Löf Type Theory

type-level programming through intuitive functions, functional dependencies is another, indeed the earliest introduced approach to enable rich type-level programming through relations. In 2017, Morris and Eisenberg acknowledged in Constrained Type Families that the current Haskell type system inevitably accepts some apparently erroneous definitions, as type families equivocally assumes totality[8].

On the other hand, F* is an ML-like functional programming language aimed at program verification[10]. At POPL 2016, Swamy et al. introduced the current, completely redesigned version of F*, a language that works as a powerful and interactive proof assistant, a general-purpose, verification-oriented and effectful programming language, and an SMT-based semi-automated program verification tool. F* is a dependently typed, higher-order and call-by-value language with a lattice of primitive effects. These monadic effects can be specified by the programmer and is used by F* to discharge verifications using both SMT solver and manual proofs[10]. In addition, it uses a combination of dependent types and refinement types for program verification and supports termination checking based on a metric of well-founded decreasing order to ensure program consistency. Dependently typed F* is further enhanced by the introduction of Dijkstra Monads to perform program verification on effectful code beyond the primitive effects by Ahman et el. at POPL 2017[1].

3 Approach and Uniqueness

To gain a better understanding of the language design decisions and verification techniques, I first carefully study 2-3 literals for each language. In general, my assessment of Dependent Haskell and F* is based on implementing and proving a wide spectrum of algorithms in both languages. These programs are written so that I could have a much more in-depth experience with both languages and explore their features more thoroughly. To begin with, in both Dependent Haskell and F*, I implement the data type of a length-indexed vector and verify various functions that support types of finite length vectors from Haskell's List module, including length, head, tail, init, last, snoc, reverse, and, or, null etc. I then focus on the verification for various sorting algorithms, such as mergesort and quicksort, and examine the capability of proving divergent functions, as in the proof of peano division with zero divisor. In the following weeks, I plan to implement more representative functions as listed in Eisenberg's dissertation Chapter 3.1-3.2 and especially focus on verifications on effectful programs. I will structure the comparison mainly focusing on three aspects : language design measured from syntactic verbosity and type system expressiveness, and library/documentation supports ; verification techniques determined through the adaptability and effectiveness of proofs ; and finally termination checking evaluated using quantified success rates as metric. As far as I know, I am the first researcher to directly compare program verification techniques between Dependent Haskell and F*.

4 Current Results

At the 45th ACM POPL Student Research Competition, Xu and Zhang presented their collaborated work on the comparison among three programing verification techniques in Dependent Haskell, Liquid Haskell and F*[12]. They conclude that among the three languages, Dependent Haskell has the most verbose syntax, but at the same time is comparably more expressive. Liquid Haskell and F*, both provide a more friendly user interface, but Liquid Haskell has several proof consistency issues while F* has some difficulties in proving divergent functions. Verification-wise, Liquid Haskell, instead of taking the type theory approach as Dependent Haskell, introduces refinement reflection and in turn supports SMT-solver automation. F*, combining the benefits of both type theory based dependently typed lemma proofs and SMT automated verifications, supports both explicit and implicit programming. Finally, contrary to Liquid Haskell and F* and indeed most dependently typed programming languages, Dependent Haskell doesn't require totality checking at compile time and instead verifies proof termination at run-time. As a partial language, it may accept proofs that diverges or errors but it guarantees the correctness of all fully evaluated proofs. As a result, Xu and Zhang advocate more collaborations between Dependent Haskell and Liquid Haskell, using F* as a reference.

Références

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Stephanie's comments:
- Well-structured abstract. It was easy for me to read through it, even though I don't have
a lot of background knowledge about the research topic.
- I'm not sure about the difference between this work and your previous work mentioned in
reference [12]. It'd be great if you could talk about it a bit more, like how much you
narrowed down the research question for this one.
- I like how you structure your abstract. The content in each section makes sense too.
- How about adding the purpose of comparing the two languages? You describe the process
really well, and also give good explanation of the languages and previous work done on this
topic, but I haven't seen your research motivation.
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